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A sequential approach for the optimization of truck routes for solid waste collection

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ABSTRACT

The main objective of this paper is to present a sequential approach involving three phases for solving the optimization problem of truck routes for the collection of solid waste. The first phase executes the grouping of arcs based on an adapted model of the p-median problem, formulated as a problem of Binary Integer Linear Programming (BILP). The second phase refers to the development of a model for the solution to the Capacitated Arc Routing Problem (CARP), formulated as a Mixed Integer Linear Programming (MILP) problem. The third phase carries out the application of an adapted algorithm of Hierholzer for sequencing the arcs obtained in the preceding phase. The proposed methodology was tested using real data and efficiently solved the problem. The results led to a reduction in the distances traveled by trucks, which could promote money savings for the public coffers, as well as a reduction in carbon dioxide emissions.

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Nomenclature

ACS	Ant Colony System
b	truck capacity
BILP	binary integer linear programming
c_{ij}	cost of the arc (i, j)
CARP	Capacitated Arc Routing Problem
CCPP	Capacitated Chinese Postman Problem
CO_2	carbon dioxide
d_{ij}	product of the distance between vertices x_i and x_j and the weight w_i
FLP	Facility Location Problem
GAMS	General Algebraic Modeling System
K	number of vehicles
MCPP	Mixed Chinese Postman Problem
MILP	Mixed Integer Linear Programming
M-VRPTW	Multi-Depot Vehicle Routing Problem with Time Windows
n	number of vertices of the graph
p	number of medians to be installed
q_{ij}	demand of the arc (i, j)
SA	Sensitivity Analysis
TSP	Travelling Salesman Problem
VRP	Vehicle Routing Problem
w_j	demand of each vertex x_j

1. Introduction

Solid waste is the technical name given to garbage and can be regarded as any material that the owner or producer no longer considers valuable enough to keep. It is composed mainly of paper/cardboard, plastics, glass, metals, textile and food/garden waste. It is the result of human activity and its amount is directly proportional to industrial intensity and population increase. Solid waste is regarded as dangerous in relation to its physical, chemical, and infectious properties. Thus, the inadequate removal and collection of waste, as well as inadequate destination and final treatment, can cause a great impact on the environment (Buah et al., 2007).

The problem of solid waste in cities encompasses several factors, such as generation, collection, processing, and disposal. Collection is the most sensitive part in the eyes of the population and needs to be very well planned, since it represents about 50% of the operating costs of public sanitation, and not less important, the trucks that carry out this task emit about 1.24 kg of CO_2/km traveled and are considered large carbon dioxide emitters in the atmosphere (Detofeno and Steiner, 2010).

So, for this planning, route optimization of the trucks that collect waste is often treated as a Vehicle Routing Problem (VRP), which basically consists in establishing and organizing efficient routes so that vehicles can deliver and/or pickup merchandise, featuring a fleet of k vehicles which may or may not be identical, with the objective of serving a set of customers with a known demand. It is associated with special cases such as the Travelling Salesman Problem (TSP) and the Capacitated Chinese Postman Problem (CCPP) (Dror, 2001).

In this work, the subject under study is considered to be a combinatorial optimization problem, known in the literature as a Capacitated Arc Routing Problem (CARP), which was first proposed by Golden and Wong in 1981. The CARP, as proposed by these authors, considers a non-negative demand associated with each arc of the road network and a set of vehicles with known capacity that must traverse the arcs making collections or deliveries relating to the respective demands. Furthermore, the capacity of the trucks must not be exceeded. The goal is to search for a set of minimal cost routes that begin and end at a single point, often termed warehouse (Golden and Wong, 1981).

The CARP includes most real life applications in cases related to the collection or delivery of products and is classified as NP-Hard. Due to this fact, heuristics are frequently used to solve the problem more efficiently. Some papers from the literature highlight problem solution alternatives. Moghadam et al. (2014) proposed a simulated annealing algorithm and a hybrid metaheuristic algorithm combining Ant Colony System (ACS) and simulated annealing for a vehicle routing and scheduling problem in a network consisting of suppliers, customers, and a cross dock; Dondo and Cerdá (2009) presented a local search improvement algorithm to solve the multi-depot vehicle routing problem with time windows (M-VRPTW) that explores a large neighborhood of the current solution to discover a cheaper set of feasible routes; Belenguer et al. (2010) used a metaheuristic based on a cutting plane algorithm and on evolutionary local search for a split-delivery problem; Laporte et al. (2010) presented a neighborhood search heuristic for a problem with stochastic demands; Mourão and Almeida (2000) proposed a heuristic combined with a lower bounding method for a problem of waste collection; Mourão and Amado (2005) used heuristics such as Path-Scanning, Augment-Merge, and Ulusoy's algorithms, and Ghiani et al. (2005) developed an approach based on a well-known cluster-first, route-second heuristic, both for the problem of waste collection; Hertz et al. (2000) presented a method based on Tabu Search algorithm; Beullens et al. (2003) used a guide local search algorithm and Lacomme et al. (2001) used a Genetic Algorithm to solve the CARP; Shanmugasundaram et al. (2011) implemented the SAVGIS (free tool) in route optimization for collection and transportation of healthcare waste in Laos; Karadimas et al. (2007) implemented the Ant Colony System (ACS) algorithm for route optimization of solid waste trucks in Athens.

According to Usberti et al. (2011), there are two ways to solve the CARP from an exact algorithm: the first one is based on a branch and bound algorithm (Hirabayashi et al., 1992), while the second one transforms the CARP into a capacitated vehicle routing Problem (CVRP) and the problem is solved using a branch-and-cut-and-price algorithm (Longo et al., 2006). However, the authors caution that these approaches can only solve specific instances of relatively small size. Other authors, such as Eiselt et al. (1995), Dror (2001), Hertz (2005), Wøhlk (2008), and Corberán and Prins (2010) expanded the CARP study and presented exact and heuristic algorithms to improve its solution.

As noted by Dror (2001), there are two versions of the CARP regarding the number of vehicles to be included in the model. In the first version, this number is a fixed parameter. In the second one, it is considered to be a decision variable, which means that the algorithms can make use of an unlimited fleet of vehicles. Welz (1994) observed that determining the existence of a feasible solution for a given fixed number of vehicles is already an NP-hard problem and thus, for the second version of the CARP, this problem becomes even more difficult, which may explain the development of many heuristics for this purpose.